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Backfill Effects on Subsurface Drainage of Toledo Soils: I. With Grass-Legume Cover

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Backfill Effects on Subsurface Drainage of Toledo Soils: I. With Grass-Legume Cover

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INTRODUCTION

This is a report of a field study in which a highly conductive backfill was created by subsoiling or by trenching and backfilling directly over drains installed 6 years earlier. The primary purpose of the study is to evaluate the effect of backfill conditions on subsurface (pipe) drainage. The soil at the experimental site is a Toledo silty clay, and its drainage characteristics are representative of many poorly drained clay soils of midwestern United States. During the period of the study, the site had a continuous vegetative cover of grasses and legumes. A companion paper will report similar investigations on an adjacent site cropped to grain.

There are two primary reasons for establishing a highly conductive backfill. One is to reduce the hydraulic resistance in the immediate vicinity of pipe drains and thus permit more rapid entry of water. Cover materials such as coarse gravel and crushed stone are occasionally used to achieve this objective. The other is to provide a hydraulic connector between pipe drains and shallow soil depths. In some cases the connector may join a permeable surface layer with the drain when they are separated by a relatively impervious subsoil. For other cases, the connector may facilitate the flow of water between shallow mole channels and deeper pipe drains.

Considerable field research has been conducted to evaluate the effect of cover materials on decreasing the hydraulic resistance in the near vicinity of pipe drains. Rand (5) used gravel over pipe drains in a clay subsoil at Brooksby Hall in England. Taylor and Goins (7) evaluated crushed stone, corncobs, vermiculite, and wheat straw as cover materials for a clay subsoil in Ohio. Hopewell (3) used gravel, wheat straw, and grass sod over pipe drains in New Zealand. These three studies showed that little improvement in subsurface drainage can be expected from adding permeable cover materials in clay soils of the humid regions. Apparently, refilling a trench with excavated clay soil provided sufficient permeability for water entry into drains.

Less research has been done on the use of a highly conductive backfill as a hydraulic connector. Trafford and Rycroft (10) studied the effect of a gravel layer over pipe drains on the performance of mole drains. Their studies showed that the gravel improved the performance of mole drains. Levesque and Hamilton (4) excavated trenches over previously installed pipe drains in a clay soil in Ontario, Canada. The trenches were filled with gravel or peat. Neither material improved drainage and crop yield.

The Toledo soil is one of the poorly drained clay soils in the Lake Plain region of Ohio and Michigan. These clay soils occur on nearly level topography and contain appreciable amounts of clay. The permeability of the plow layer is usually many times greater than that of the subsoil. Both internal and surface drainage are slow. Heavy rains may result in ponding of depressional areas or saturating the plow layer for several days. Often these conditions exist where subsurface drains have been installed.

A highly conductive backfill may improve the subsurface drainage of many poorly drained clay soils. Fall plowing is a common practice for clay soils of the Midwest. Until seedbed preparation is carried out the following spring, the plow layer is usually very porous and permeable. Water can move quite readily through the plow layer in a nearly horizontal direction until the water table recedes to plow depth. Thus, a highly conductive backfill should be especially effective in removing excess water from the plow layer during this period. The effectiveness of the backfill at later dates would depend on the permeability of the plow layer, and the latter will be strongly influenced by tillage, equipment compaction, and structural stability of the soil.

A highly conductive backfill is necessary for satisfactory performance of mole drains. The mole drains (channels) are formed with a special plow at depths of 50 to 60 cm, usually in soils that contain pipe drains. The mole channels are formed above and across the pipe drains. A highly conductive backfill permits rapid transmission of water from the mole channel to the pipe drain.

The information given in this report is based on field studies initiated in 1977. These studies are still underway, and this paper reports the progress made from 1977 through 1979. A portion of the data reported herein were given in an earlier publication by Taylor *et al.* (8).

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[2]The authors thank James L. Fouss and Ronald C. Reeve who helped install the experimental drains in 1971 and Charles C. Willer, David E. Kopcak, and John M. Maul who assisted in the field evaluations.

TABLE 1.—Physical Properties of Toledo Silty Clay at the North Central Branch, OARDC, as Reported by Schwab, et al. (6).

Horizon	Depth cm	Sand	Silt	Clay	pH	Bulk Density g/cm^3	Volumetric Moisture Content at Indicated Suction 60 cm	15 atm
		Percent					Percent	
A_p	0-20	3	46	51	5.8	1.22	41	21
B_{1g}	20-32	3	43	54	6.4	1.39	42	25
B_{21g}	32-50	4	41	55	6.7	1.43	46	27
B_{22g}	50-75	3	38	59	7.0	1.45	46	28
B_{23g}	75-95	2	40	58	7.0	1.48	44	30
C_{11}	95-125	5	48	47	7.2	1.49	43	28
C_{12}	125-160	3	45	52	7.5	1.40		25
C_2	160-175	3	44	53	7.5			

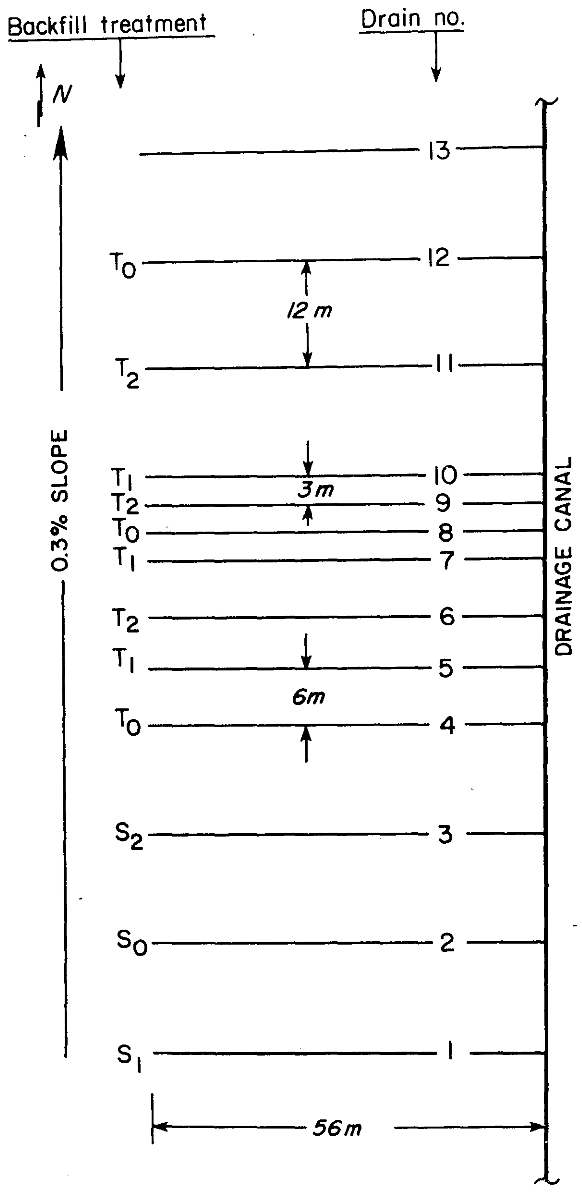

FIG. 1.—Field layout of subsurface drainage system used in the studies. The symbols S_0, S_1, and S_2 represent subsoiling treatments while T_0, T_1, and T_2 represent trenching treatments.

SITE AND SOIL

These studies were conducted at the North Central Branch of the Ohio Agricultural Research and Development Center. This branch is located about one-half mile from Sandusky Bay. The soil is a Toledo silty clay and requires subsurface drainage for consistently large crop yields. The soil is classified as a poorly drained, fine, illitic, Mollic Haplaquept. The clay content is approximately 50% in the plow layer and approaches 60% in the lower B-horizon at the 50-cm depth. A detailed analysis of the soil physical properties at the North Central Branch is shown in Table 1.

The saturated hydraulic conductivity of this soil decreases with depth, as reported by Hoffman and Schwab (2) and Taylor *et al.* (9). The following hydraulic conductivity values were reported by Taylor *et al.* (9).

0-20 cm depth	3.2 to 5.5 cm per hour
20-170 cm depth	0.2 to 0.5 cm per hour

These values apply for situations when the soil has been thoroughly wetted such as the spring months. The plow layer (0-20 cm depth) conductivity varies considerably with time, depending on tillage and soil compaction.

The experimental site is an 0.8-hectare field with 19 subsurface drain lines (Fig. 1). Only 13 drain lines were used in this study since the outlets for 6 lines were submerged. The latter condition was due to a higher elevation of Lake Erie than when the drains were installed. These drains were installed in November 1971 with a floating-beam mole plow. The drains are 5-cm diameter corrugated plastic tubing, 56 m long, installed at an average depth of 40 cm and an average grade of 0.1%. A detailed description of the drainage facilities was reported by Fausey (1). The drains have six rows of slotted openings that are slightly elliptical in shape. The slots are about 10 mm long and 1 mm wide. There are a total of 285 openings and 28 cm^2 opening areas per meter length of drain.

Prior to drain installation, the field was leveled in the direction of the drains. A slope of 0.3% exists across the lines. No dikes were made between the drain lines, with the result that surface water cannot pond to any significant depth. All drains discharge individually into a drainage ditch where flow rates can be measured manually at the outlets.

The field was plowed in March 1972 and planted to corn in May 1972. Following corn harvest, the site was again plowed in January 1973. Because of the rising level of Lake Erie, the site was too wet to plant corn in spring 1973. The site was disked several times to control weeds and then seeded to wheat in October 1973 with an intercrop seeding of timothy and red clover. Since harvesting the wheat crop in July 1974, the field has not been farmed except to occasionally clip the clover, timothy, and volunteer grasses. A nearly complete vegetative cover has existed on the site since 1975.

FIG. 2.—A trench is being excavated directly above an existing subsurface drain to establish treatments T_1 and T_2. The trench width is 20 cm and its depth is approximately 35 cm. The excavated soil was used to fill the trench.

EXPERIMENTAL

Trenching and Backfilling

Drains numbered 4 through 12 were used for the trenching and backfilling studies, with these drains spaced at 3, 6, and 12 meters (Fig. 1). The following three backfill treatments with the indicated symbols T_0, T_1, and T_2 were established on August 18, 1977:

- T_0 Control—No alteration in soil overlying the drains since installation in November 1971 (Drains 4, 8, and 12).
- T_1 A trench excavated directly above and to within 5 cm of the drain and then backfilled with the excavated soil (Drains 5, 7, and 10).
- T_2 Same as T_1 except trench was hand spaded to expose the upper one-third circumference of drain before backfilling (Drains 6, 9, and 11).

For the T_1 and T_2 treatments, a 20-cm wide trench was excavated with a chain trencher over the entire length of the perforated drain line to an average depth of 5 cm above the drain (Fig. 2). To establish the T_2 treatment, the trench was then hand spaded to a greater depth in order to expose the upper one-third of the drain line. The spaded soil was not removed from the trench but was left in a rough condition. After 2 days the exposed trenches were backfilled with the excavated soil by using a tractor-mounted blade. The backfill was not compacted. The soil moisture content during trench excavations was near the lower plastic limit but the soil did not adhere to the trencher blades.

Before assigning backfill treatments to the drains, a uniformity analysis of flow rates was made for all drains. A comparison of the maximum flow rates was made under ponded flow conditions. The variation among flow rates for the nine drains was small (see Fig. 13, Appendix), and each backfill treatment was assigned to each of the three drain spacings. For a particular spacing, the drains were selected at random for the treatments T_0, T_1, and T_2.

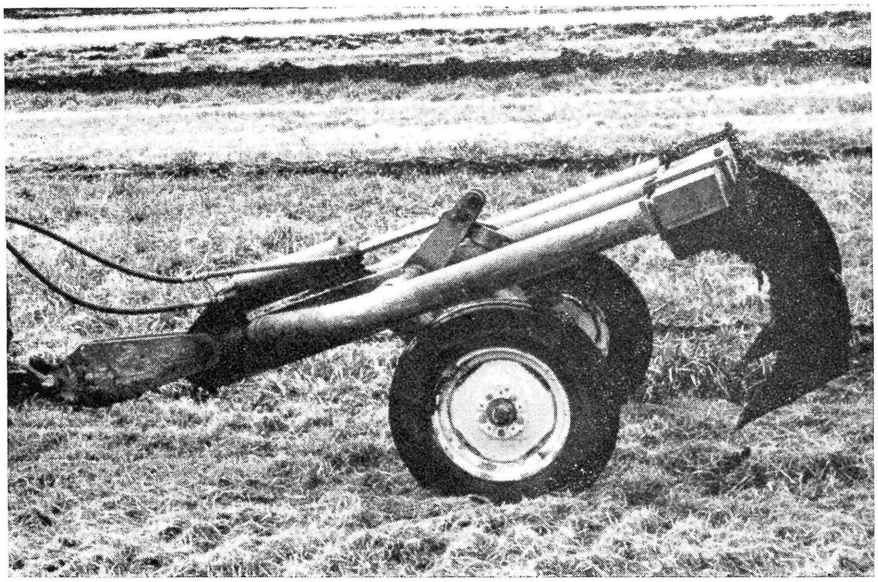

FIG. 3.—Chisel plow used in subsoiling directly over the drains. For this study one of the two chisels was removed and the remaining one shifted to the center of the frame.

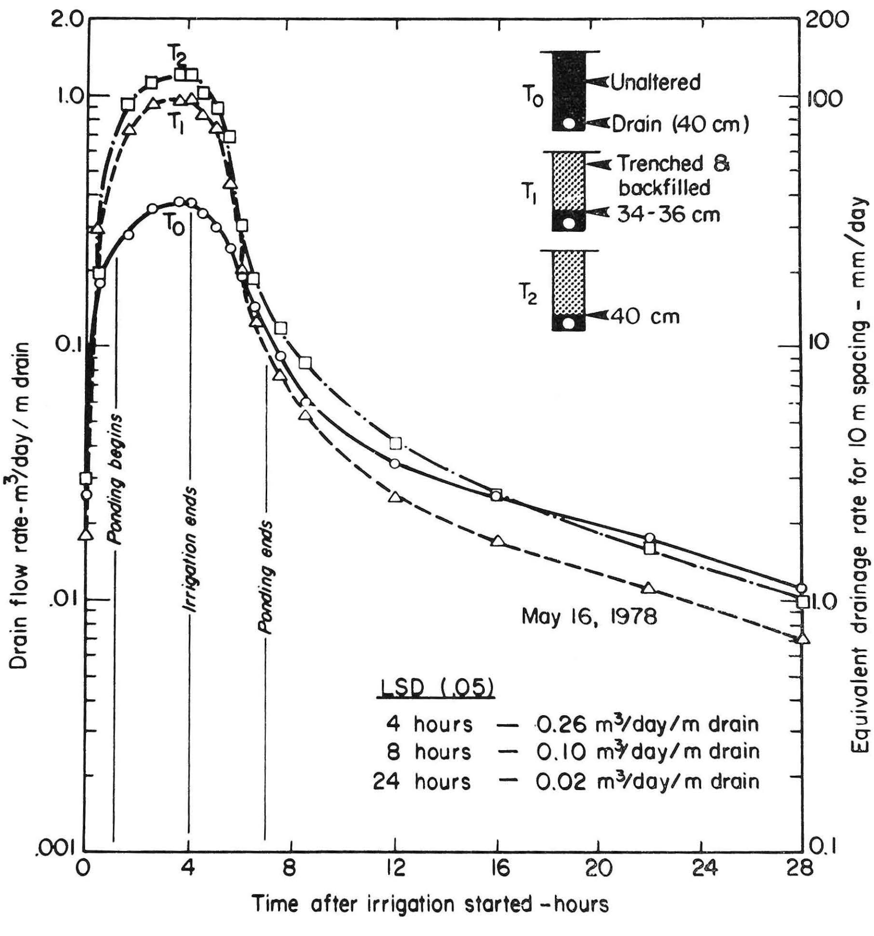

FIG. 4.—Effect of backfill treatments on drain flow rates for the irrigation of May 16. Each curve represents the average flow rate for three drain lines. The symbol T_0 indicates unaltered backfill while T_1 and T_2 indicate trenching and backfilling to approximate depths of 35 and 40 cm, respectively.

Subsoiling

The following three subsoiling treatments with the indicated symbols S_0, S_1, and S_2 were initiated on Oct. 7, 1977.

S_0 Subsoiling to a depth of 15-18 cm (Drain Number 2).

S_1 Subsoiling to a depth of 25-28 cm (Drain Number 1).

S_2 Subsoiling to a depth of 33-36 cm (Drain Number 3).

Subsoiling treatments were made with a single-shank chisel plow shown in Fig. 3. For the S_0 and S_1 treatments, a single run of the plow was made directly over the drain line at the indicated depth. For the S_2 treatment, a first run of the plow was made at about 20 cm, followed by a second run in the same furrow at a depth of 33-36 cm. The soil moisture at the time of subsoiling was near the plastic limit in the subsoil but was drier in the surface layer. The subsoiled furrows were left in an open, rough condition.

Procedure

At various dates, drain flow rates were measured following excess water applications by sprinkler irrigation. The sprinklers were placed at a spacing of 12 by 12 meters and provided an application rate of approximately 0.5 cm per hour. Prior to flow rate measurements, a pre-irrigation of about 3 to 5 cm was made to elevate the water table and initiate drain flow. Another irrigation was made the following day until all drains achieved a steady flow rate. At the end of each irrigation, there would be 15 to 80% ponding in the field. Drain flow measurements were made manually at the outlets with a bucket and stopwatch. These measurements were discontinued when flow rates became too small to measure or showed only small changes with time. The percentage of the ground surface covered with water was estimated visually.

Water table elevations at 20 m from the drain outlet were measured for T_0 and T_2 treatments by using a series of 1.5 cm diameter perforated pipes installed to a depth of 50 cm. These pipes were installed at horizontal distances from the drain that were equivalent to 0, 1/10, 1/4, and 1/2 drain spacing. The piezometric pressure head inside the drains spaced at 6 m was measured by use of 1.5 cm diameter solid wall pipes that were installed about 2 cm inside the drain and extended above the ground surface. The junction of the pipe with the drain wall was sealed with caulking compound.

Irrigation and drainage water samples were collected during an irrigation of Sept. 6, 1978, in order to determine soil sediment and other residues. Additional samples were collected during a rainfall on April 13, 1979. A portion of the water sample was filtered through a micropore filter having openings of 1 μ diameter. The sediments retained on the filter were oven dried and weighed.

RESULTS OF TRENCHING AND BACKFILLING

The flow data shown in Fig. 4 are typical of those obtained for each irrigation. The maximum (peak) flow rate for drains that were trenched and backfilled (T_1 and T_2) exceeded those for drains without an altered backfill (T_0) by a factor of 2 to 4. The peak flow rates always occurred at the time the irrigation ended. An exponential decline in flow rates was obtained as the ponded water disappeared over a period of 2 to 4 hours. As soon as ponding ceased, differences in flow rates among the three treatments became statistically insignificant.

During periods of surface ponding, both treatments T_1 and T_2 gave greater flow rates than the T_0 treatments, these differences being statistically significant at the 1% probability level. For the same periods, the T_2 treatments gave greater flow rates than the T_1 treatments, with these differences significant at the 5% level.

The maximum drain flow rates obtained before and several dates after initiating the backfill treatments are shown in Fig. 5. The large flow rates brought about by trenching and backfilling remained relatively unchanged for almost 2 years. There was no significant reduction in flow rates with time for the untrenched drains (T_0) or for drains trenched to within 5 cm of the drain and backfilled (T_1). A 20 to 25% reduction in flow rate occurred after 90 weeks for those drains where the altered backfill extended to the drain (T_2).

The percentage ponding given in the upper part of Fig. 5 is the average value for drains 4 through 12 when irrigation ended. The percentage ponding varied somewhat from one irrigation to another as well as within the field for a given irrigation. As might be expected, greatest ponding occurred where drains were spaced 12 m and least where the spacing was 3 m. Because of the increased drain flow rates due to backfill alterations, ponding did not exceed 50% for three of the irrigations made subsequent to treatment establishment.

A comparison of the amount of water removed by the three treatments under ponded and nonponded conditions is given in Fig. 6 for three irrigations. The interval of 4 hours following irrigation represents the maximum time required for ponded water to be removed for any irrigation. During the period of ponding, drains with an altered backfill removed two-

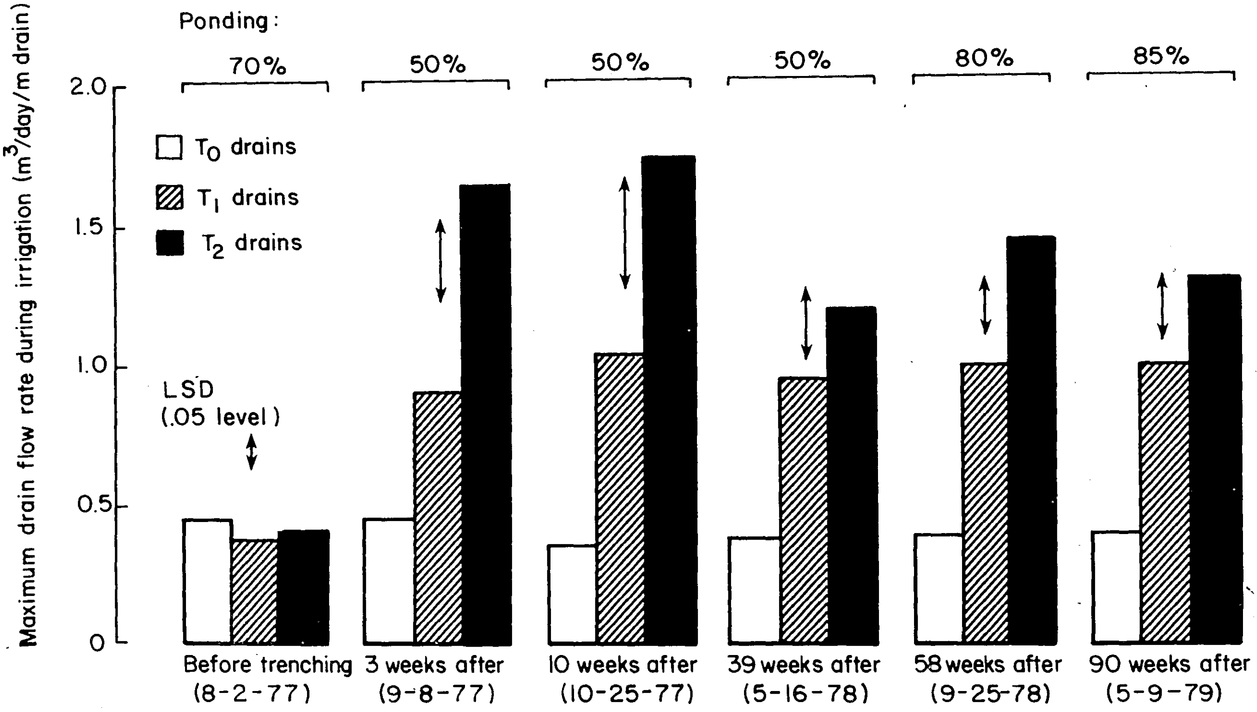

FIG. 5.—The effects of trenching and backfilling directly over drains on maximum drain flow rates at several dates. Each bar represents the average flow rate for three drains. The symbols T_0, T_1, and T_2 represent, respectively, untrenched drains, trenched to within 5 cm of drain, and trenched to within 5 cm of drain plus hand spading to drain depth.

to four times as much water as drains without a backfill. In the absence of ponding, there was no difference in the amounts of water removed by the three treatments.

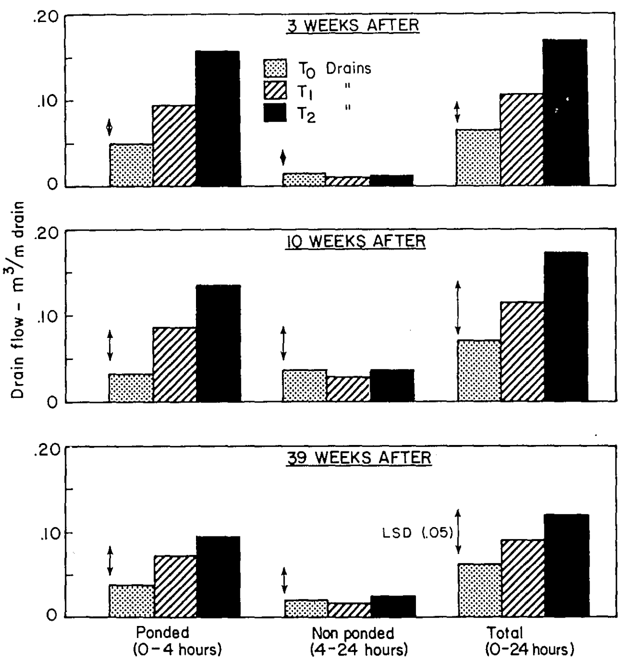

FIG. 6.—Effects of trenching and backfilling treatments on water removed by drains during ponded and non-ponded conditions. The symbols T_0, T_1, and T_2 represent the backfill treatments. Each bar represents the average water removed by three drains.

A comparison of water table drawdown for the drains with unaltered backfill (T_0) and those altered to drain depth (T_2) is given in Fig. 7 for the irrigation of Sept. 25, 1978. There was no significant difference in water table drawdown between the two treatments. Since there was good surface drainage in the experimental area, ponded water could easily move downslope across drains. If dikes had been installed midway between drains, it is likely that draw-

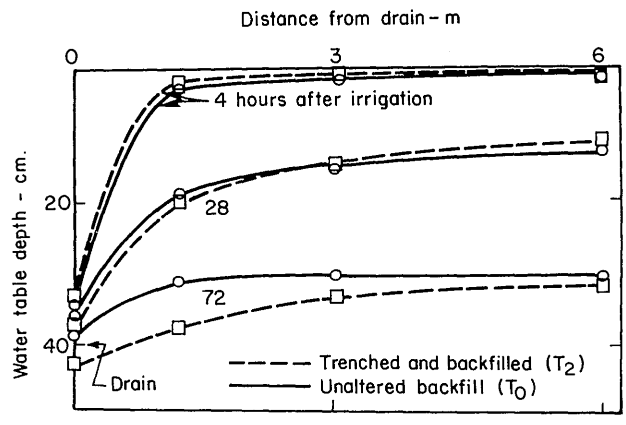

FIG. 7.—Water table drawdown for trenched (T_2) and untrenched drains (T_0) following the irrigation of Sept. 25, 1978.

down would have been more rapid for the trenched drains. The shape of the water table for both treatments is quite typical for these soils. The water table surfaces were essentially horizontal except in the immediate vicinity of the drain.

The relationship between drain flow rates and water table elevation at the midspacing is shown in Fig. 8 for the T_0 drains. When there was ponded water or the midspacing water table elevation was within the upper 2-4 cm of the plow layer, the flow rates were relatively large. There was an exponential decline in drainage rates as the water table receded in the plow layer. Apparently the large flow rates resulted because ponded water flowed almost vertically downward in the region directly above the drain. While the data given in Fig. 8 are for drains with unaltered backfill (T_0), similar results were obtained for the T_2 drains. The data for T_0 drains are shown here since these data were the most complete ones for drawdown.

From measurements of piezometric pressure head inside the drains, it was found that the hydraulic capacity of the drains was so small that the full potential of the backfill treatments could not be evaluated. The pressure measurements were made for the T_0 and T_2 drains at 6 m spacing for the irrigations of Sept. 6 and 25, 1978. Both T_0 and T_2 drains were flowing under positive pressures (*i.e.,* backpressure) for several hours during both irrigations. The mean pressure head for the T_0 drain was 12, 8, 6, and 4 cm of water, respectively, at 0, 1, 2, and 4 hours after irrigation. Comparable values of pressure head for the T_2 drains were 39, 35, 7, and 5 cm, respectively.

For purposes of comparison, a static reservoir of water extending upward from the drain to the ground surface would give a pressure head of approximately 40 cm of water at drain depth. The maximum pressure head that could develop inside the water-filled drain due to elevation differences is about 5 cm of water. Thus, the positive pressures inside the drains are primarily a result of positive pressures in the soil surrounding the drain. The greater pressures in the T_2 drains are undoubtedly a consequence of low hydraulic resistance in the backfill.

When irrigations were made, sediment concentrations in the drainage water were quite small. During the period of maximum flow rates for the irrigation of Sept. 6, 1978, the average sediment concentrations were 9, 7, and 8 mg per liter, respectively, for the T_0, T_1, and T_2 treatments. These small sediment concentrations are probably a consequence of low water application rates, the good vegetative cover, and absence of tillage.

Sediment concentrations were about 20-fold greater during rainfall on April 13, 1979. At the time of sampling approximately 1.2 cm of rain had fallen and some ponding had occurred. The average sediment concentrations for the three drains were 190, 200, and 180 mg per liter, respectively, for T_0, T_1, and T_2 treatments. Respective drain flow rates were 0.40, 0.60, and 0.60 m^3 per day per meter length of drain. Differences in sediment concentrations for the three treatments were not statistically significant at the 5% probability level.

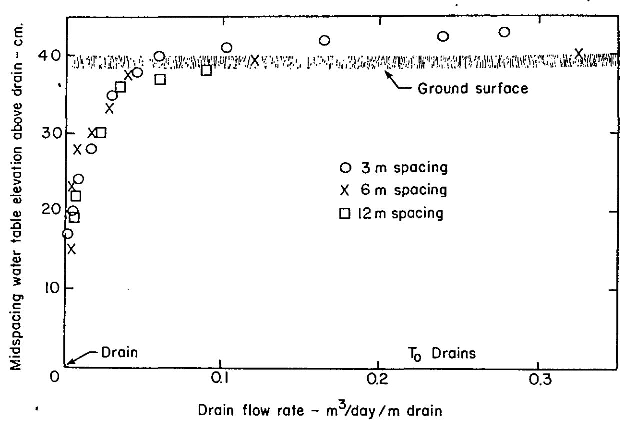

FIG. 8.—Relationship between water table elevation and drain flow rates for untrenched (T_0) drains. Irrigation of May 16, 1978.

The relatively large sediment concentrations during rainfall are probably a result of high rainfall intensities that occur when vegetative cover is a minimum and soil moisture contents are high. The combination of these two factors favors soil particle detachment and suspension. The sediment concentrations for April 13 were only one-third as large as those obtained at the same time on an adjacent fall-plowed area (data not reported herein).

RESULTS OF SUBSOILING

Each of the three subsoiling treatments brought about appreciable fracturing and loosening of the soil in the upper 20 cm. A vertical cross section of the furrow immediately after subsoiling can be seen in Fig. 9. The deepest subsoiling (S_2) resulted in the formation of an oblong shaped channel just above the drain. This mole-like channel was approximately 7 cm wide and 7 to 15 cm high. The slit connecting the channel to the surface soil was partially filled with loose soil. Subsoiling at the intermediate depth (S_1) resulted in the formation of a partial channel in the subsoil. The most shallow subsoiling (S_0) fractured the soil but did not form a channel.

During the 3 weeks immediately following subsoiling, about 2.5 cm of rainfall had fallen. This was in addition to 8 cm of irrigation water. The channel was still present at this time, but the slit was partially filled. During the 10 months following subsoiling, there was winter freezing and thawing, spring rainfall of some 20 cm, and a 6-cm irrigation on May 16, 1978. By this time the channels had completely disappeared but fracture planes were still visible in the soil.

The drain flow data shown in Fig. 10 are typical of those obtained for all irrigations. Each drain had the greatest flow rate at the time when irrigation was terminated. At such time the water table was near the ground surface and some ponding had occurred. Maximum flow rates were proportional to the depth of subsoiling, namely $S_2 > S_1 > S_0$. Within 4 hours following an irrigation, ponding disappeared and flow rates decreased nearly ten-fold. A second ten-fold decrease in flow rates occurred by the end of 24 hours.

The maximum drain flow rates obtained at several dates are shown in Fig. 11. These flow rates were measured under ponded conditions either after a rainfall or immediately following an irrigation. The ponding shown in the upper part of the graph was the average percentage of the land area covered with water between drain numbers 1 and 4 (see Fig. 1).

There was a large increase in flow rates for each of the three drains as a result of subsoiling. This can be seen by comparing the flow rates before and after subsoiling. The large increase in flow rates as a re-

FIG. 9.—A vertical cross-section of the furrow for treatment S_2 immediately after subsoiling. Note the slit in the upper part of the photograph and the channel-like cavity in the lower part. Subsoiling depth was 33 to 36 cm.

sult of subsoiling at the most shallow depth (S_0) indicates the low permeability of the surface layer when it is not plowed for several years. For most irrigations after subsoiling, the relative flow rates for the S_0, S_1, and S_2 drains were approximately 1, 1.5, and 2, respectively. The relatively low flow rate for the S_1 drain 3 weeks after subsoiling was a result of not sufficiently ponding the land area in the vicinity of this drain. For a particular drain, there was no significant change in flow rates from the 26th through the 82nd week following subsoiling.

The amounts of water removed by the drains under ponded and nonponded conditions are given in Fig. 12. Before subsoiling there was essentially no difference in the amount of water removed by the three drains. Subsoiling over the drains resulted in approximately a three-fold increase in water removal during a 24-hour period. A major portion of this increase occurred when ponding existed in the field. Under ponded conditions, the deeper subsoiled drains (S_1 and S_2) removed 50 to 100% more water than the drain with shallow subsoiling (S_0). The S_1 drain had the greatest flow during nonponded conditions since it received water from a greater land area (see Fig. 1).

The amount of sediment in the drainage water was essentially identical to that obtained from drains which were trenched and backfilled. For the irrigation of Sept. 6, 1978, the average sediment concentration was 14 mg per liter for the three drains. For the April 13, 1979, rainfall the sediment concentra-

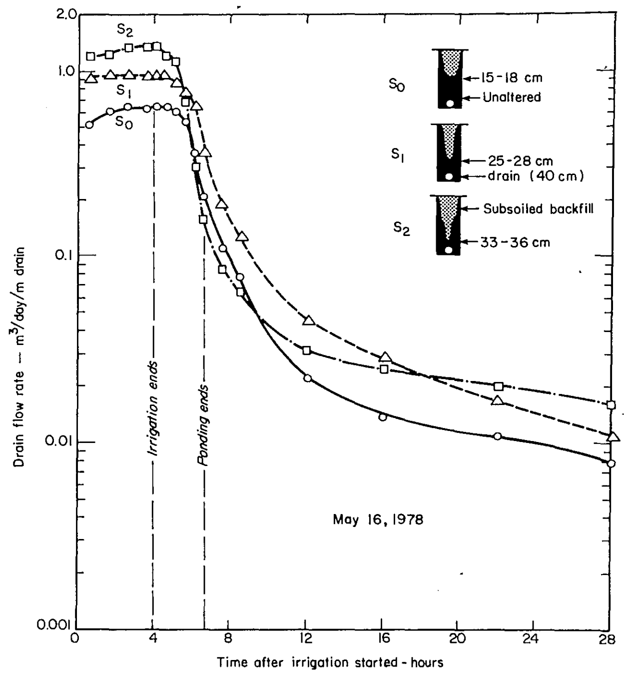

FIG. 10.—Drain flow rates as affected by subsoiling directly above drains to different depths. The symbols S_0, S_1, and S_2 represent subsoiling to approximate depths of 16, 26, and 34 cm, respectively. Drain depth is 40 cm.

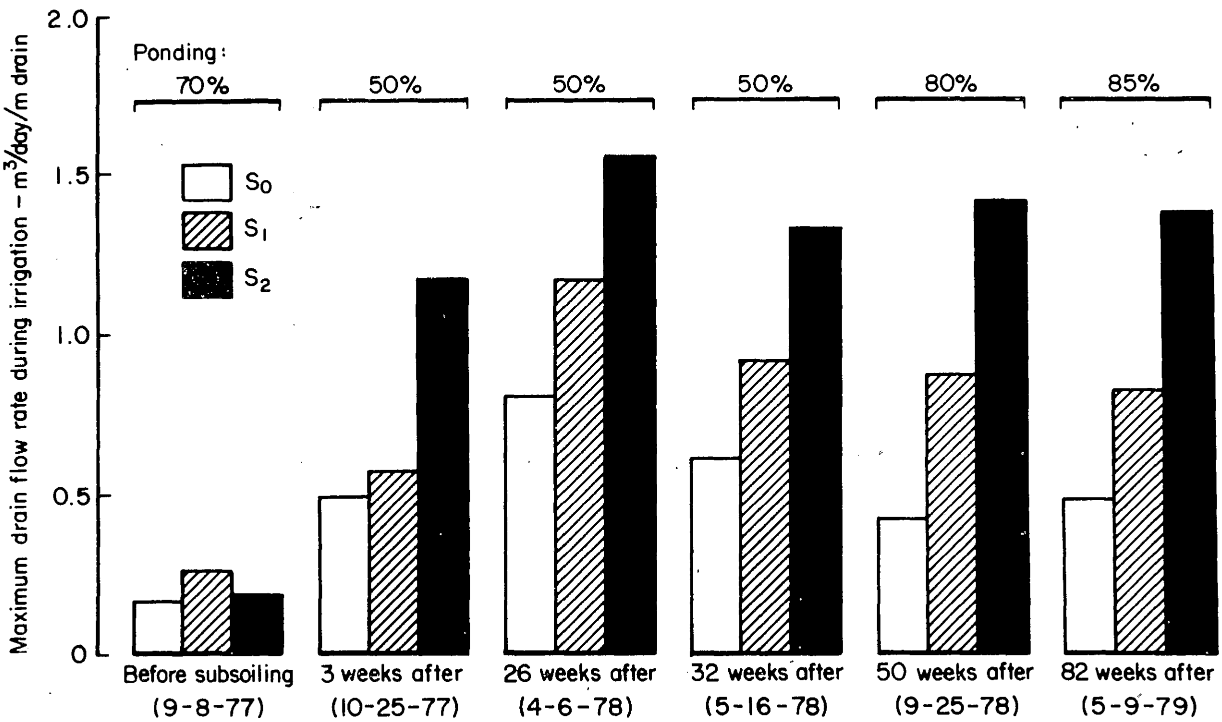

FIG. 11.—The effect of subsoiling depth on maximum drain flow rate at various dates after subsoiling. The symbols S_0, S_1, and S_2 represent subsoiling to approximate depths of 16, 26, and 34 cm.

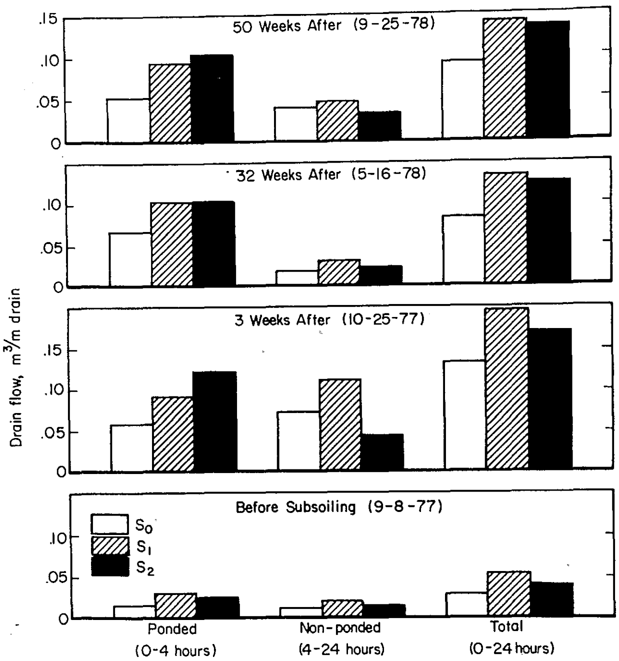

FIG. 12.—Effects of subsoiling directly above drains on water removal rates during ponded and non-ponded conditions. The symbols S_0, S_1, and S_2 represent subsoiling to approximate depths of 16, 26, and 34 cm, respectively.

tions were 190, 190, and 170 mg per liter, respectively, for the S_0, S_1, and S_2 drains. Respective drain flow velocities at the time of sampling were 0.55, 1.05, and 1.20 m^3 per day per meter length of drain.

DISCUSSION

For conditions at the experimental site, the major effect of subsoiling or trenching and backfilling was to rapidly conduct ponded water to the drain. Although trenching and backfilling resulted in greater water removal, it did not increase the rate of water table drawdown, apparently because surface drainage was quite adequate at the site. Ponded water could move across the ground surface from areas with untrenched drains to areas with trenched drains. If dikes had been installed midway between drains, for example, it is quite likely that drawdown would have been more rapid for the trenched drains. While drawdown was not measured for subsoiled drains, it would appear that drawdown results would be quite similar to those that were trenched.

The drainage effects of backfill alterations reported herein are probably greater than would prevail under grain farming. Tillage would result in greater amounts of detached soil particles that could clog channels and fissures in soil. Equipment traffic would bring about soil compaction. There would be less moisture depletion by grain crops, and this would bring about faster deterioration of soil aggregates. Each of these three processes would have a greater effect on the altered backfill than on undisturbed soil.

The effectiveness of subsoiling for increasing backfill permeability will depend on the amount of soil fracturing, and the latter will be greatly influenced by soil moisture contents at the time of subsoiling. Because of substantial amounts of soil moisture removal from this site by the grass-legume mixture, soil fracturing was probably much greater than one would expect where more shallow rooted, annual crops were grown. In some additional subsoiling studies at the North Central Branch where corn was grown continuously for 3 years, the effect of subsoiling directly over drains had little effect on drain flow rates (data not reported herein). The subsoiling was done in October after corn harvest. The authors' observations were that soil moisture contents were too high to permit a high degree of soil fracturing.

The effect of subsoiling depth on drain flow rates has some practical implications. The large increase in flow rates immediately following shallow subsoiling (S_0) indicates that a fractured surface layer is highly permeable. Plowing these soils should increase the amount of water flowing into subsurface drains and decrease the amount moving across the ground surface. The subsoiling results also show that it is not necessary to extend a permeable backfill completely to the drain in order to increase drain flow rates. If subsoiling over drains should become a recommended practice, it will not be necessary to subsoil to drain depth where the danger exists for mechanical damage to the drain.

The results of these studies indicate that surface water removal from slowly permeable soils can be greatly enhanced by a permeable backfill. This has practical implications for the flat, clay soils that are slowly permeable and where surface water ponds for extended periods in depressional areas. Hydraulic connectors between the subsurface drains and the more permeable topsoil could greatly reduce the surface water accumulation and lead to more uniform drying within the field. Various methods could be used to achieve such a permeable zone. Retrenching over existing drains may not be economically feasible, but chiseling or subsoiling at regular intervals may be justified. Backfilling the trench with gravel or other stable, porous materials may also be feasible, depending on local availability and cost. Additional studies will be required to evaluate the longevity of enhanced permeability above subsurface drains resulting from these various options.

SUMMARY

A highly permeable backfill was created by trenching and backfilling and by subsoiling directly over drains installed 6 years earlier in an Ohio lakebed clay soil. The drains were 5 cm diameter plastic tubing installed at a 40 cm depth. The experimental site had a vegetative cover of grasses and legumes. The full potential of backfill alterations could not be evaluated because of the limited hydraulic capacity of the drains.

Trenching and backfilling increased flow rates by a factor of two to four during periods of ponding but had no effect on flow rates after ponding ceased. Trenching to drain depth gave greater flow rates than trenching to within 5 cm of the drain. Trenching and backfilling had no effect on water table drawdown, apparently because of excellent surface drainage that diverted ponded water from untrenched drains to adjacent trenched ones. After 90 weeks, drain flow rates were essentially unchanged where trenching extended to within 5 cm of the drain but had declined 20 to 25% where the trenching extended to the drain.

Subsoiling to 16, 26, and 34 cm depths, respectively, gave stepwise increases in drain flow rates during periods of ponding. Subsoiling to 34 cm resulted in drain flow rates that were approximately the same as trenching to drain depth. The flow rates for subsoiled drains have not declined significantly after 82 weeks.

It is quite probable that the characteristics of the experimental site have affected the results reported herein. The continuous vegetative cover and the lack of tillage and equipment traffic should be favorable to maintaining large flow rates following the backfill alterations. The vegetation also would have aided in depleting soil moisture to a considerable depth and thus permitted more effective fracturing of the soil during subsoiling. Since clay soils have relatively high structural stability, the longevity effects of backfill alteration would be much greater than for soils high in sand or silt.

REFERENCES

1. Fausey, N. R. 1975. Numerical model analysis and field study of shallow subsurface drainage. Ph.D. dissertation, The Ohio State Univ.
2. Hoffman, G. J. and G. O. Schwab. 1964. Tile spacing prediction based on drain outflow. Trans., Amer. Soc. Agri. Eng., 7(4):444-447.
3. Hopewell, H. G. 1953. Tile drainage investigations in New Zealand. I. Interim report on investigations into the effect of various methods of refilling tile trenches. New Zealand J. Sci. and Tech., 35A:249-261.
4. Levesque, M. and H. A. Hamilton. 1967. L' efficacite d'un systeme de drainage souterain avec remplissage poreux dans un sol argileux de Kapuskasing. [The efficiency of a subsurface drainage system with porous filling material in a Kapuskasing clay soil.] Can. J. Soil Sci., 47:55-65.
5. Rand, J. G. 1974. The value of permeable backfill (PF) based on field experiments. *In* proceedings of the conferences at Stoneleigh and Church Stretton on the use of permeable backfill. Ministry of Agriculture, Fisheries and Food, England. Field Drainage Experimental Unit, Tech. Bull. No. 74/11, pp. 19-28.
6. Schwab, G. O., T. J. Thiel, G. S. Taylor, and J. L. Fouss. 1963. Tile and surface drainage of clay soils. I. Hydrologic performance with grass cover. Ohio Agri. Exp. Sta., Res. Bull 935.
7. Taylor, G. S. and T. Goins. 1967. Field evaluation of tile drain filters in a humid region soil. Ohio Agri. Res. and Dev. Ctr., Res. Circ. 154.
8. Taylor, George S., S. S. Hundal, and N. R. Fausey. 1980. Permeable backfill effects on water removal by subsurface drains in clay soil. Trans., Amer. Soc. Agri. Eng., 23(1):104-108.
9. Taylor, G. S., E. Stibbe, T. J. Thiel, and J. H. Jones. 1970. Hydraulic conductivity profiles of Toledo and Miami soils as measured by field monoliths Ohio Agri. Res. and Dev. Ctr., Res. Bull. 1025.
10. Trafford, B. D., and D. W. Rycroft. 1974. The natural soil as trench backfill. Ministry of Agriculture, Fisheries and Food, England. Field Drainage Experimental Unit, Tech Bull. No. 74/9.

APPENDIX

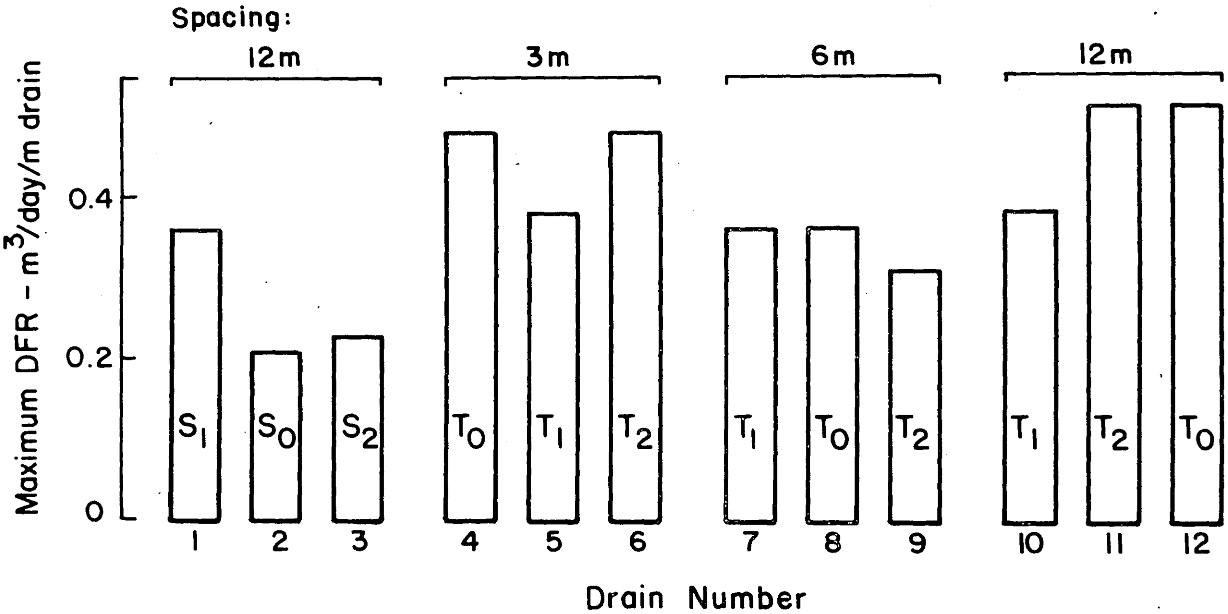

FIG. 13.—Maximum drain flow rate (DFR) for each of the 12 drains before initiating the trenching and subsoiling treatments. Irrigation of August 2, 1977. The symbols S and T indicate, respectively, the subsoiling or trenching treatments assigned to each drain.

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Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres